A Progressive Formalization of Tacit Knowledge to Improve Semantic Expressiveness of Biodiversity Data

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Abstract. The majority of biodiversity data available on the Web are structured, lacking unstructured features such as tacit knowledge, images, audios, text documents, among others. Tacit knowledge can be used to add more expressiveness to ontologies. To achieve that, the knowledge needs to be elicited and formalized and further incorporated into an ontology. This paper aims to present a Progressive Formalization Schema (PFS) to formalize tacit knowledge into different levels of granularity.

Keywords: Knowledge, Formalization, Semantic, Ontology, Biodiversity Data.

1 Introduction

There is lack of unstructured biodiversity data, e.g., legacy knowledge of the researchers, the bushmen, fishermen, local guides, etc., and therefore there is unexplored potential to add value to data currently available. These data are found in expert's[1] mental models[2] (EMMs) or field notes and tend to be lost in the process of information transfer. EMMs are not expressed in traditional databases, since this knowledge is rarely represented/formalized and was learned and documented through years of the expert's experience, but it can consist of important and also relevant information that can help to guide future actions.

Based on the above facts, it is imperative the need of tacit knowledge formalization to improve semantic expressiveness of biodiversity data, together with, biodiversity ontologies.

Knowledge formalization in this context, refers to making knowledge processable or understandable by computers. The knowledge may be presented at different levels

[1] An expert can be understood as an individual who has valuable knowledge that can be used by someone or an organization [Kendal and Creen, 2016].

[2] According to Susan Carey [Carey and Spelke, 1994], "It represents a person's thought process for how something works (ie. the understanding of the world around). Based on incomplete facts, past experiences and even intuitive perceptions. They help to define actions and behaviors, influence what will be considered most relevant in complex situations and define how individuals confront and solve problems."

of formalization, for example, from text documents to explicit rules [Baumeister et al., 2011].

A simple inference of a fishman experience, such as, “*the presence of swamp rice grass (Leersia hexandra) in the river, indicates the likely occurrence of malaria in the region, since this vegetation provides suitable conditions for the proliferation of Anopheles darlingi, the malaria vector*” can generates new knowledge or guides new knowledge acquisition [Albuquerque, 2016]. Additionally, this tacit knowledge could be used to infer structured data organized in structuring instruments of knowledge, such as ontologies or databases.

This paper presents a method named Progressive Formalization Schema (PFS), that allows to navigate the elicited and formalized knowledge for further use (to improve the degree of formalization or to recover semantic lost). Also, it allows access to knowledge at different levels of granularity and minimizes the semantic losses that may occur in the process of Knowledge Representation (KR).

In this research, the addition of tacit knowledge of an expert into formal ontologies [Guizzardi, 2005] was performed. The tacit knowledge considered is the scientific, according to Collins (2001), which is not necessarily formalizable, but must be, in some way, capable of systematization; and in agreement with the fundamental conceptual structure of the domain. Tacit knowledge into ontological schemas is innovative and has the purpose of increasing the expressiveness of ontologies.

This paper is organized as follows: in section 2, a characterization of the research context is presented; the related works to this research are described briefly at section 3; PFS is presented in section 4; an EMM’s formalization describing each step of the PFS for OntoBio is presented in section 5, followed by the conclusions of this work at section 6.

2 Characterization of the Research Context

The knowledge acquisition process is not always organized or systematically explainable. Some knowledge is acquired, and the entire process cannot be fully comprehended. This happens because part of the knowledge is considered tacit. In this research, we consider the tacit scientific knowledge, that refers to the knowledge or skill that can be passed among experts by interactions, but difficult to be expressed or described in formulas, diagrams, verbal descriptions or instructions for action [Collins, 2001]. In this sense, it is knowledge based on scientific information, however it is related to the experience and competence of the expert, therefore difficult to systematize and represent. It concerns the knowledge that is better transferred and assimilated informally. By its subjective nature, it is difficult to formalize tacit scientific knowledge, since it is dynamic and can only be accessed through direct collaboration and communication with people who have knowledge in the same domain. This is what makes the process of transferring this type of knowledge so difficult, costly and uncertain, because it is experts dependent. If it is well explored and these experiences can be transmitted to others, this type of knowledge can become a differential for semantic richness. Only part of scientific tacit knowledge can be formalized since it makes use of informal communication [Albuquerque, 2016; Leite, 2006].

From the interaction between explicit scientific knowledge - registered scientific knowledge, scientific literature - and tacit scientific knowledge - what specialists know, learned and are communicated through interactions and unstructured means -, it becomes feasible to create a new scientific knowledge [Nonaka and Takeuchi, 1995].

Knowledge formalization, also referred to, as KR, which is an area in Artificial Intelligence concentrated in formalizing knowledge to be computable. It represents knowledge to facilitate inference [Romanov, 2005].

Humans have been developing many formalisms for KR. These formalisms can range from a purely textual formalism to graphical representations (conceptual maps) [Novak and Gowin, 1984].

However, the most powerful formalisms use more complex techniques (logic, semantic networks, frames, scripts, production rules, ontologies, among others) [Sowa, 2000]. They are mostly based on mathematics, philosophy and cognitive science. These disciplines provide basic ideas of how the world is perceived and modeled.

Mathematics provides a compact set of principles widely shared in society. These shared principles allow for the construction of powerful expressions.

Philosophy studies the nature of knowledge and how to create and manage it, and to do so, some mathematical tools are designed and used. For example, ontology and logic are two building blocks of KR. Therefore, KR can be defined as the application of logic and ontology to the task of developing computable models of some domain [Sowa 2000]. Logic and ontology provide the formal mechanisms required to make significant models easily shareable and usable by computers [Lofting, 2015]. Ontologies are of particular interest in this research to organize, structure and thus represent knowledge [Albuquerque, 2016].

In this work, KR considers the knowledge found in the mental models of biodiversity experts (EMMs) and becomes explicit through an PFS. Despite all the formalisms possibilities for representing knowledge, it is important to emphasize that tacit knowledge is richer than any description of it, and eventually loss of semantics is expected during the process of formalization.

3 Related Work

The concepts presented in knowledge PFS are referenced in the literature in a broader context.

McGuinness (2003) presents ontologies and provides criteria necessary, prototypical, and desirable for developing simple and complex ontologies, focusing on the ontology languages and environment.

Uschold and Gruninger (2004) presents different types of ontologies, from terms to the general logic. The main difference between them is the manner of specifying the meaning of terms. This is a continuum of kinds of ontologies. Moving along the continuum increases the amount of meaning specified and the degree of formality.

Although they do not propose transitions between particular types or propose to use them together in the development of intelligent systems.

Millard et al. (2005) present an approach that consists of a vector-based model of the formality of semantics in hypertext systems, where the vectors represent the translation of semantics from author to system and from system to reader, foreseeing semantic loss (intermediation). Its scale defines a subset of KR instruments ranging from simple text to RDF data.

Furthermore, Schaffert *et al*. (2006) understand that knowledge can be represented on many different levels of formality and in a wide variety of formalisms (similar to PFS). They classify ontologies using three properties: model scope, acceptance of the model and the level of expressiveness, where the latter defines a subspace of knowledge PFS. The level of expressiveness ranging from lightweight ontologies, with lists of terms as the least significant representative, to heavy-weight ontologies with very significant restrictions as the most significant.

Gruber (2008) correlates the degree of knowledge formalization with the depth of inference and discusses the exchange cost/benefit of the captured knowledge.

Baumeister *et al*. (2011) describe a knowledge formalization continuum to help domain specialists during the knowledge acquisition phase. To make use of the knowledge formalization continuum, the agile use of KR within a knowledge engineering project is proposed, as well as transitions between the different representations, when required.

Nalepa et al. (2011) discuss a new formalized KR for rule-based systems called XTT2, a hybrid KR that combines decision diagrams with extended decision tables. The structure of XTT2 constitutes a hierarchical KR consisting of lower level knowledge components, where specification is provided by a set of rules working in the same context, and at the higher level, where the decision diagram defines the overall structure of the knowledge base.

Klein *et al*. (2015) identify a need for a framework-independent solution to formalize design knowledge and derives corresponding objectives to be fulfilled by this solution.

4 Progressive Formalization Schema (PFS): An Overview

In this research, it is adopted a PFS to assist knowledge acquisition and to formalize the knowledge elicited.

The PFS provides to the knowledge engineer flexibility in KR of the EMM. This formalization schema emphasizes that the usable knowledge ranges from very informal (such as text and images) to very explicit representations (such as logical formulas or ontologies). Also, PFS allows knowledge engineers to focus on a certain degree of knowledge formalization and offers a versatile understanding of the process of formalization, since it supports the representation of knowledge at various levels of granularity.

In a PFS, the same knowledge of a domain can be presented in several forms of representations, where adjacent representations are similar to each other, for example, tabular data and XML. However, the most extreme representations are quite different, e.g., text versus logical rules. Gradual transitions in the degree of formalization of the same knowledge are possible, but the knowledge to be modeled is not subjected to sudden changes or discontinuities. Although the PFS can be considered as a schema that involves several levels of granularity of formalized knowledge, the represented domain knowledge remains the same. The PFS also emphasizes that knowledge is subject to changes, a continuous development in which a change can also result in a new representation. The PFS helps domain experts and knowledge engineers to visualize the data, even simple as text and multimedia, as more formal knowledge that can be transformed by gradual transitions when requested. The data provided by textual documents represent one of the simplest formal possibilities and functional models concentrated knowledge in a formal level.

Figure 1 illustrates techniques for KR in a PFS. This list of representations does not intend to be exhaustive, and nor the described order of representations of data and knowledge intended to be explicit. In fact, it does not seem possible to define the total order of representations in general. The order described was motivated by the possible level of expressivity related to built systems reasoning capacity using a particular representation. For example, text can be used for retrieval and conventional search based on keywords, while texts with semantic annotation enables semantic queries and browsing. At the IV Quadrant, the rules-based knowledge supports more complex reasoning capacity.

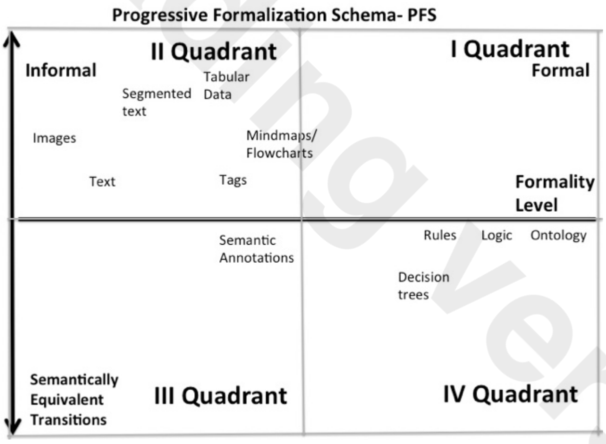

Figure 1. Possible KR of PFS. Adapted from [Baumeister *et al*., 2011]

Each level of formalization has its advantages and disadvantages. For example, textual knowledge is easier to be elicited (when explicit) and is often already available in the domain. But the automated reasoning using the textual knowledge is not possible with current methods; and knowledge can be recovered only through strings matching methods but not by applying semantic queries. Logical rules or models are suitable for automated reasoning, and queries can be processed at the semantic level. In contrast to textual knowledge, the acquisition of rules and models is typically a complex and timeconsuming task. Authors of rules need to be trained before constructing knowledge bases on the explicit level with regard to the principles of knowledge engineering and modeling tools. For this research's purposes, the conceptual framework requires the adoption of an ontology object of study to guide the formalization process, mainly in the IV Quadrant of Figure 1, rules, logic and ontology. We used OntoBio, a formal ontology applied to biodiversity data, developed in a research initiative involving the Institute of Computing at the Federal University of Amazonas and INPA's Biological Collection Program (Albuquerque, 2015). OntoBio was modeled conceptually through OntoUML language (Guizzardi, 2005).

For a given knowledge base, which is formalized using a particular KR, there is often semantically equivalent transitions (indicated by the Formality Level axis in Figure 1). The knowledge is often taken to a semantically equivalent representation to allow extensions for the domain knowledge.

Between the two extremes (text versus logic) there is a wide range of KR formats in different degrees of formalization. Any instance of the formality level can be the most useful representation for a specific application design.

For a given formalization project, it is important to select the most suitable level of formalization as representation target. Since knowledge (or its fragments) is generally available in textual or tabular form, the development process is centered on bringing the existing forms to an appropriate level. Usually, it is necessary to fill in the missing pieces of knowledge, but its original nature remains. Thus, the choice of a more formal representation may require a more explicit description of knowledge and can enrich the resulting knowledge with additional semantics. Each transition is a separate operation that modifies the KR. However, the mental model of knowledge remains the same. It can be observed that in each transition of the level of formalization, there may be loss of semantics expressiveness as the resource for KR used in each level of formalization (e.g., conceptual maps, first-order logic, ontologies) cannot be able to represent certain aspects of knowledge.

Transitions between different levels of formalization, for example, text to semantic annotations can be made manually and sometimes in semi-automated manner.

The direction of the transition to a less formal KR is required, for example, to analyze/evaluate the developed knowledge bases, or, to retrieve knowledge that has become hidden between the different levels of KR. Thus, it enables a backtracking, from the more formal knowledge level to a least formally, enabling revisits and knowledge recovery on different levels of granularity. At this point, a visualization of a less formal knowledge base, however precise, helps to understand the semantics of implemented knowledge.

From a more informal to a more formal KR, we have a representation of knowledge as ontology to be compared with OntoBio. The typical direction in knowledge engineering is the transition from barely structured/unstructured data to a more explicit representation. It is possible to backtrack (from the more formal knowledge level to the least formal) with the purpose of identifying tracks of lost knowledge in the process of formalization and which may be used in the acquisition of new knowledge.

The PFS considers that knowledge is usually represented at different levels of formality. The schema supports the use of knowledge engineering in an arbitrary level of formality and offers possible knowledge transitions to a level where the cost/benefit principle [Lidwell et al., 2003] is the best.

The PFS does not require the formalization of the whole knowledge collection (in this study, EMM), but the performance of transitions in parts of the collection when it is possible and recommended. Consider the fact that sometimes not all parts of a domain can be formalized at a specific level or that the formalization of the whole domain of knowledge is too complex.

Even considering the cost/benefit, there is a need to transform pieces of knowledge into a formal level where costs (knowledge engineering) are minimized and the benefits of using are maximized. Therefore, the PFS must not only support transitions of particular pieces of knowledge but must also be able to maintain references amongst parts less and more formalized of the entire collection of knowledge.

5 EMM's Formalization

This work deals with knowledge expressed in biodiversity EMMs, specifically ichthyologists. During the knowledge formalization schema through a PFS, based on OntoBio, the following KR are adopted, as presented in Figure 2.

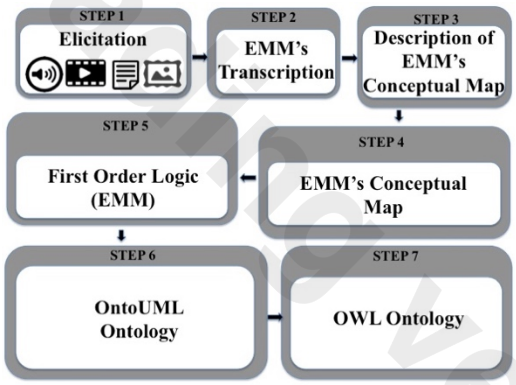

Figure 2. PFS Model.

Steps 1 and 2 are represented with the media of the interview used to elicit knowledge and its transcription, respectively. A record of the knowledge elicitation media and its transcription must be kept for further use. Step 3 is the description of the conceptual map according to the analyst view. Step 4 represents the conceptual map designed by the analyst (ontology engineer); that is the analyst view of what was elicited. Step 5 represents the conceptual map description in First-Order Logic, FOL; 6 represents conceptual map description on a foundation ontology and 7 represents the conceptual map description in Ontology Web Language (OWL). Steps 1 and 2 deals with knowledge elicitation and were discussed in detail in [Albuquerque *et al.*, 2016]. Steps 3, 4, 5, 6 and 7 are briefly presented in the following sections.

5.1 Conceptual Map Description: An Analyst View of EMM

This description is subjected to the analyst understanding of the EMM and decision of which knowledge and how it is going to be modelled. During the transition between the transcription of interview and the description of an EMM, semantic losses may occur.

For illustration, the following conceptual map description elicited during an interview with ichthyology experts is used:

EMM – To fish jatuarana (*Brycon* genus) use jauari seed (*Astrocarium* genus).

This EMM can be understood in two ways: (a) jauari seed can be used as a bait to fish jatuarana (most ever it is understood that jauari can be used as bait, but in fact, it is jauari's seed); or (b) jauari can be used as food to jatuarana and food is important in the food chain to attract other species.

5.2 Conceptual Map Tool for EMM's Representation

Some computational tools are used to help the process of knowledge elicitation such as xLine, IThought, and SimpleMind, among others [Clark, 2011]. These tools produce conceptual maps used to organize and represent knowledge. Special attention is devoted to some tools influenced by the Semantic Web and ontology. Recent versions of PCPACK support the export of RDF, while plug-ins for knowledge elicitation in Protégé [Noy *et al*., 2001] interoperate with the Protégé-OWL plug-in [Wang et al., 2006]. There are also CmapTools extending initiatives to provide support for viewing and editing OWL ontologies.

Any of these tools are suitable to represent EMMs as conceptual maps, since no semantic support is demanded at this phase of the research and they are only used as a graphical source to view the EMMs. Figure 3 presents the conceptual map of the EMM described in section 5.1 using SimpleMind.

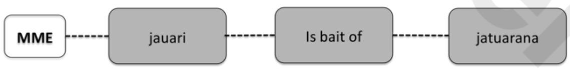

Figure 3: MME represented as a conceptual map.

5.3 Representing EMM in First Order Logic (FOL)

The reason why logic is relevant to KR and reasoning is that logic is the study of relationships-language linking, truth conditions and rules of inference [Brachman and Levesque, 2004]. Specifically, it will be used at this stage of the research FOL or First Order Predicate Calculus (FOPC), which is only a starting point, a simple logic to formalize knowledge [Brachman and Levesque, 2004].

The language of FOL is built around objects and relationships. FOL has been important for mathematics, philosophy and artificial intelligence, because in these fields of knowledge, much of everyday human life, can be thought of as objects and the relationships between them. FOL can also express facts about objects. This allows to represent general laws or general rules [Russel and Norvig, 2010]. Following, is the elicited EMM, now expressed in FOL.

```
  EMMa – ∀ Jauari ⇒ ∃ Jatuarana | [MaterialEntity (Jatuarana) ∧
CollectionMethod (Bait(Jauari)) ∧ Has((Bait(Jauari), Jatuarana)]
```

Or,

```
  EMMb – ∀ Jauari ⇒ ∃ Jatuarana | [MaterialEntity (Jatuarana) ∧
BioticEntity (Jauari) ∧ Eats(Jauari, Jatuarana)]
```

Such representations drive us to some considerations:

• The formalization of knowledge in steps 5, 6 and 7 of PFS must use a domain ontology to guide the process. At these steps, the knowledge engineer can already identify similar concepts and relationships as well as those that do not exist in the domain ontology;

• The representation of EMM in FOL may present semantic loss in consequence of limitation of the KR feature.

5.4 Representing EMM in OntoUML: Level of Analysis

The OntoUML ontological schema of EMM is designed similarly to OntoBio's schema.

Guizzardi proposed a conceptual modeling language that includes as a modeling primitive, ontological distinctions proposed by UFO-A [Guizzardi, 2005]. This language (now called OntoUML) was built following a process in which: (i) the metamodel of the original language (in this case, the UML 2.0) is fixed to ensure an isomorphism in its mapping to the structure defined by the reference ontology (in this case, UFO-A); (ii) secondly, the axiomatization of the foundational ontology is transferred to the language metamodel through formal restrictions built into this metamodel. The purpose was to ensure that the language only accept as grammatically valid models those models that satisfy (in the logical point of view) the axiomatization of UFO, that is, those models that are considered valid according to this theory. In addition, Guizzardi [Guizzardi, 2005] proposed a set of methodological guidelines for the creation of ontologies using OntoUML language. The use of OntoUML is justified because it is an ontology conceptual modeling language based on foundational ontologies.

Both UFO foundational ontology and OntoUML language has been used in several case studies for building domain ontologies, and the development of applications based on these ontologies. Examples of areas covered include electrocardiology [Gonçalves *et al.*, 2009)], exploration and production of oil [Guizzardi, 2009], biodiversity [Albuquerque et al. 2015], among others.

The ontological schema should be designed using a tool with UML graphical support. The tool used in this step of the PFS was Enterprise Architect. Once the ontological schema is completed, it must be exported as XMI file and then imported by the OntoUML LightWeight Editor (OLED) tool (now called Menthor), where an OWL file can be generated.

OLED is an environment for the development, evaluation and implementation of domain ontologies, using OntoUML based on UFO. OLED supports the Sparx Enterprise System Architect models.

Figure 4 and 5 present the OntoUML schema for EMMa and EMMb respectively.

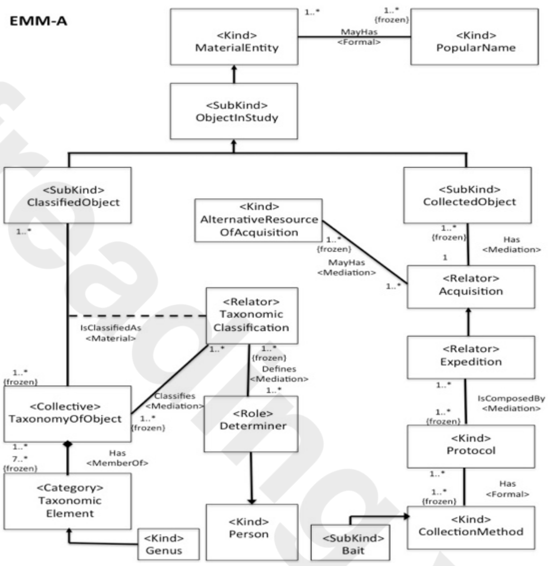

Figure 4: The OntoUML schema for EMMa.

5.5 Representing EMM in OWL: Level of Application

W3C recommends the use of OWL for developing ontologies in application level [McGuinness and Harmelen, 2004]. Protégé [Wang et al., 2006] is the OWL editor used in the PFS. It is a tool developed in Java language, which supports plugins to extend its functionality and also provide a flexible basis for the development of prototypes and applications efficiently. One of the main features of this tool is to support two ways of modeling and implementing ontologies: based on frames and on OWL language.

Although OLED allows the automatic generation of OWL code of the ontological schema designed, it is important to remember that a language in the level of analysis for ontologies as OntoUML has greater power of expressiveness than a language for ontologies in the level of implementation, such as OWL. Thus, a code generated automatically in OWL may not reflect the reality modeled, requiring adjustments to maintain the integrity of which has been modeled, thus justifying the use of Protégé for this. This is a recurrent issue in the development of ontologies that still requires research and solution.

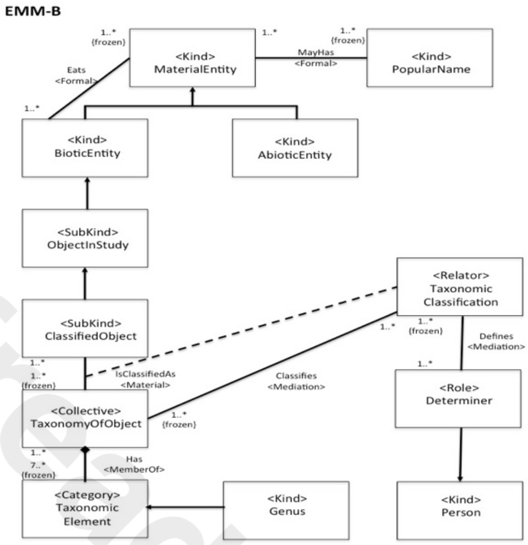

Figure 5: The OntoUML schema for EMMb.

Figure 6 illustrates a part of the PFS related to the EMM presented in this paper. Others EMMs used in our experiments, together with OntoUML schemas and OWL codes can be found at `https://andreaalb1993.wixsite.com/ontobio`

There is more than one way to understand the knowledge and, consequently, more than a way to formalize it. This implies that the same EMM can have more than one PFS associated to it. The knowledge engineer should select a PFS according to the need of a specific application within the domain.

In Figure 6, jauari is understood as a kind of bait. Bait is a specialization of the collection method adopted to capture a living organism (EMM-A).

If jauari is understood to be in the food chain of jatuarana, the associated PFS presents another configuration as shown in Figure 7.

Figures 6 and 7, show the semantics loss in the several levels of KR used in the PFS. For example, the fact that the part of jauari that attracts jatuarana is the seed (and not the bark of the trunk, or the fruit, or leaves, or fruit pulp). However, it is possible to visualize from the original flow of formalization, that the simplest level of KR (illustrated here by the management of the medias that store elicited knowledge and can make use of tags to facilitate the management process, STEP 1) to the currently considered more formal (ontology, STEP 7), the loss existed in the transition from one form of representation to another, but the knowledge is still the same and can be recovered when change the direction of the flow of the different formalizations presented (light gray arrows, backtracking).

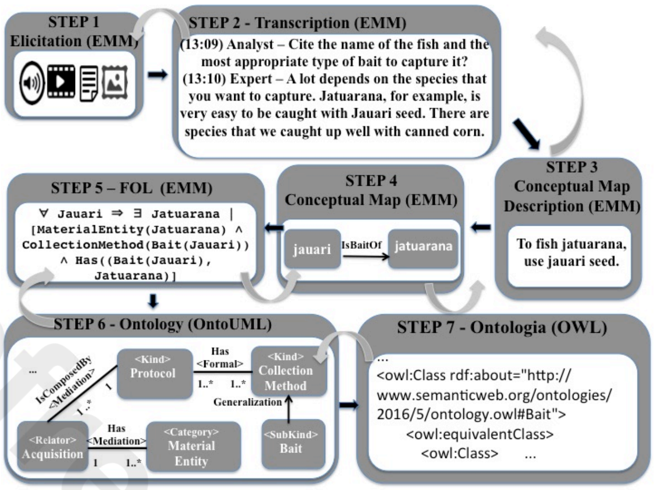

Figure 6: PFS from EMM. Jauari as bait.

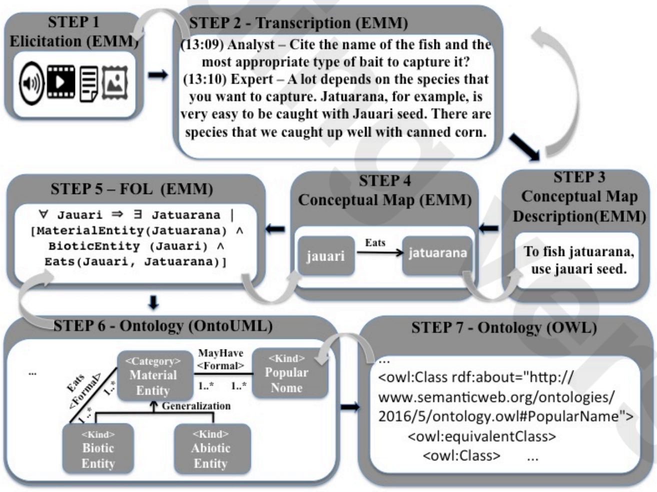

Figure 7: PFS from EMM. Jauari as food.

6 Conclusions

This work presented contributions in the field of knowledge management which comprise: a new method to formalize scientific tacit knowledge, PFS, and; its use with automatic tools that are able to structure knowledge, such as, database, ontologies, semantic networks, intelligent heuristics mechanisms, etc.

The use of the PFS provides technological advancements, bringing a range of research possibilities, which include: a) generation of new knowledge; b) identification and classification of parameters and processes outputs for decision-making; c) development of mechanisms for data preservation and organizational memory; and d) data enrichment for use in the process of analysis and synthesis.

There are still limitations regarding semantic expressiveness in the PFS, due to various levels of granularity of knowledge, imposing loss of expressiveness in the transition between the different levels of formalization. To solve that, it is necessary to develop a method to measure the threshold for semantic acceptable loss that does not compromise the quality of the formalization.

An important issue for knowledge formalization in our scenario is that, since the transcription of EMM's are based on informal communication, the EMM's comprehension is subject to the knowledge engineer's interpretation. It means that the same EMM can be formalized in different ways.

The PFS permits to navigate the formalized knowledge in its different levels of granularity to retrieve missed parts of it or even use the PFS in another moment when acquiring additional knowledge.

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